A GIS Decision Support System for Crop Cultivation

Full paper

Watanyoo Suksa-ngiam
Claremont Graduate University
Watanyoo.suksa-ngiam@cgu.edu

J. Kimani Mbugua
Claremont Graduate University
Joseph.mbugua@cgu.edu

Samir Chatterjee
Claremont Graduate University
Samir.chatterjee@cgu.edu

Abstract

Most farmers in Northeastern Thailand leave their land fallow during the dry season because they do not have adequate information on which dry-season crops to grow where. Without adequate information and guidelines for dry season farming, farmers in Northeastern Thailand will continue to leave their farms fallow. This research creates a decision support tool that helps farmers identify the best-suited dry season crops for their specific areas, and provides them with information on the best practices for growing the identified crops, and marketing information for the crops. GIS and remote sensing literature is used to develop a solution to the problem. Two experts who evaluated the algorithm that the decision support tool is based on indicated that the algorithm is useful and logical. However, the experts recommended that an accuracy test to validate the decision support tool be undertaken before it is introduced to Thai farmers.

Keywords

Decision support system, crop suitability, Thai farmers, design science research

Introduction

Food crises are listed by the World Economic Forum (2015) as one of the most highly impactful risks that the world is likely to experience in the near future. By 2050, the world needs to produce 50% more food than what is currently being produced for the projected world population of about the 9 billion people (The World Bank, 2015). Consequently, the issue of world food production is one of the urgent global problems which governments, public and non-public organizations, and farmers must address.

Most of Thailand rice, particularly Jasmine rice, is produced in the northeastern region. In 2003, for example, approximately 69.2% of agricultural land use in the region was dedicated to rice cultivation (National Statistical Office, 2003). However, the yield of rice per area is comparatively low when compared with other regions in Thailand (Titapiwatanakun, 2012). In addition, most farmers in this region rely on rain and thus can only grow rice for one season in a year (Chainuvati & Athipanan, 2001). Rice yields per hectare in the region vary, depending on the cultivation system used. The highest yield is achieved under irrigation systems during the wet-season, followed by the yields under rain-fed-only systems during the wet-season. Lastly, the lowest yield of rice occurs under irrigation systems during the dry season (Thanawong, Perret, & Basset-Mens, 2014).

To earn a living and provide for their families, farmers in the Northeastern region of Thailand need to grow crops on their farms throughout the year. Unfortunately, during the dry season the majority of farmers in this region cannot grow rice because they lack the means to access water for irrigation (Thanawong, Perret, & Basset-Mens, 2014). Thus most farmers are forced to leave their farms fallow during the dry season and move to construction sites in the urban areas in search of jobs (Craig & Pisone, 1985).

Because these farmers traditionally grow rice, they usually do not know what other crops they can grow during the dry season. Currently, the available guidelines about dry season cropping only give general recommendations about the crops that can be grown during the dry season. The guidelines provide a list of dry season crops such as cassava, jute, mulberry, soybean, mung bean, peanut, jute, and sesame (Chainuvati & Athipanan, 2001), but they do not indicate what crops are best suited for specific areas. In addition, the guidelines do not provide crop husbandry information that would help farmers learn how to manage and nurture the crops, nor do they provide economic and marketing information for the listed crops. Thus, given the low yields of rice during the dry season and the reliance of rice cultivation on the unreliable climatic conditions, there is a need for farmers in different parts of Thailand's Northeastern region to know what other crops they can grow to optimize their land use throughout the year.

The ultimate purpose of this research is to build a decision-support system that enables farmers in the Northeastern region of Thailand identify the best-suited dry season crops for their areas and provides them with crop husbandry and marketing information for the identified crops. The research seeks to address the following questions: How can dry season crop choices for specific areas in Northeastern Thailand be determined? Can a webmap decision-support tool help farmers identify the best-suited dry season crops for their specific areas? And, how useful would the webmap decision support tool be? This paper addresses only the first question while the other two will be covered at the completion of the research project.

Literature Review

Becu, Perez, Walker, Barreteau, and Page (2003) provided a crop choice multi-agent system model by accounting for both social and biophysical conditions. The model was built upon a data set of small area in the Northern region of Thailand (43.6 km2). This method is limited to small areas and is thus would be unsuitable for the entire region of Northeastern of Thailand.

Pinter et al., (2003) studied practices of agriculture management where they used data from ground, air, and space platforms to study how the environment influences plants in the USA. However, this research aimed at predicting the yield of plants based on remote sensing predictors and did not provide suggestion on how it can be applied to farming.

Ekasingh, Ngamsomsuke, Letcher, and Spate (2005) adopted a data mining technique to investigate how farmers make decision in northern Thailand. They used social, economic, and biophysical factors in their model. The area of interest was small areas in Chiang Mai and Lamphun provinces of Thailand. They used surveys of households to collect data. Consequently, this kind of research is limited in terms of time, money, and the size of areas covered.

Similarly, Ekasingh and Ngamsomsuke (2009) built a data-mining algorithm to provide a crop choice model for famers in Thailand. They used a decision tree model that accounted for biophysical factors, household resources, and crop characteristics. The study was conducted in two small areas from two provinces: Chiang Rai (Northern Thailand) and Loei province (Northeastern Thailand). The researchers surveyed 507 farmer families living in the two areas. Although this research was costly, it only covered smaller areas.

Qingyuan, Chao, Zhenghua, and Zhen (2007) used remote sensing to provide a decision support system for China's famers. The system provides information about water consumption, fertilizer, and pesticide to the farmers. However, the system only provides information to the farmers but it does not enable them to make choices.

Moniruzzaman (2015) studied how crop choice model was influenced by climate conditions. The author collected 11,389 famers in Bangladesh. Logit regression models were used to analyze the data. This paper provided general idea on how famers made decisions. It did not suggest crop choices to farmers. In addition, even though the author used a big data set from Bangladesh Bureau of Statistics, the study did not account for farmers local spatial conditions.

The aim of this research is to provide crop choices for farmers in Thailand's Northeastern region. Cassava, mung-beans, watermelon, baby corn, and peanuts can be grown during the dry-season in the region (Chainuvati & Athipanan, 2001; Polthanee & Marten, 1986). The research focuses on areas in the region where irrigated crops cannot be grown.

Cassava is chosen as a choice for farmers. In the northeastern region of Thailand, cassava can be grown after rice cultivation particularly in upland areas (Polthanee & Marten, 1986). The optimum soil temperature for cassava is between 25-29 degree of Celsius (fao.org, 2000), and the annually average temperature of the soil is about 20°C (Ratanawaraha, Senanarong, & Suriypan, 2000). When cassava is grown in the dry season, it does better in areas where the soil moister is slightly high. However, the soil should be slightly deeper in light-texture, heavy and wet (fao.org, 2013). Because cassava can be grown in poor quality soil, it is viewed as a crop that may exacerbate the quality of soils especially if grown in most soil conditions (Idhipong et al., 2012). Sandy loam and loamy-sand texture soils are suitable for cassava.

Cassava grows well in sandy loam to loamy-sand texture soils. The soils should ideally be moderately to excessively drained, but the crop also does well in poor soils that have a subsurface hardpan (Caldwell, Sukchan, & Ogura, 2005).

Watermelon is a fruit that can be grown in an entire year (thailandforvisitors.com, 2015). The maturity of watermelon can be between 65 and 90 days (Simpson, 2015) which is suitable for plating in the Northeastern Thailand during the dry-season. Watermelon can be grown in the upland areas of the region (Craig & Pisone, 1985). Farmers grow watermelon before rice cultivation because they can get the benefits of residual fertilizers (Limpinuntana, 1985). The crop does best in a hot, dry climate where mean daily temperatures range from 22 to 30°C (fao.org, 2015b). It is possible to grow watermelons in different types of soils; however light, sandy, well-drained, and fertile loam soils are the most suitable (Vinje, 2012). The best conditions for melons are well-drained, sandy loam soils, slightly acidic soils (pH 6.0 – 6.5). When melons are grown in more acidic soils, their foliage turns yellow and they do not form complete flowers (Rosen & Fritz, 2015).

Peanut is a crop that can be grown for the entire year. It is a short-life plant. The optimum maturity period is about 140 days (Hollis, 2010). Even though it can be grown in upland areas, peanut does not do well in low-soil fertility area (Sukharomana & Dobkuntod, 2003). Optimum growth occurs where mean daily temperatures range from 22 to 28°C. Reduction in yield occurs where temperature are above 33°C and below 18°C (fao.org, 2015a). The most suitable soils for peanuts are light, sandy loams with a pH of 5.9–7 (wikipedia.org, 2015).

Mung bean can be grown both in the upland and low land areas of the northeastern Thailand after rice cultivation (Polthanee & Marten, 1986). Mung beans grow best within a temperature range of 20 to 40°C (Morton, Smith, & Poehlman, 1982). The suitable conditions for mung beans are fertile sandy and well-drained loam soils. They require slightly acidic soils (pH 6.2 – 7.2). However, mung beans do not grow well in poorly drained clay soils. In addition, the crops do not grow well with alkaline soils (Oplinger, Hardman, Kaminski, Combs, & Doll, 2015).

Baby corn grows best in loose well-drained soils. Soils suitable for baby corn has a wide range of pH, and the crop can also grow in acidic soils but not in wetlands with poorly drained soils. The optimal temperature for baby corn is between 24 and 35 °C (volkerkleinhenz.com, 2006).

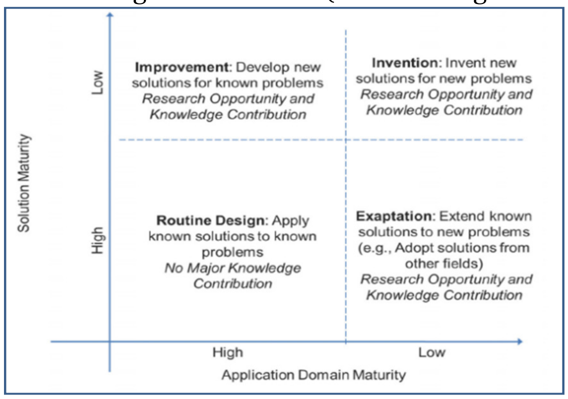
The Artifacts

This research creates two artifacts. One of the artifacts is a crop choice algorithm that determines the suitable areas for each given crop based on the climatic requirements of soils, irrigation, and temperature. While this algorithm will run in the back-end, the other artifact will be instantiated as an interactive online webmap portal for Northeastern Thailand. A farmer will be able to locate his home area on the webmap and use the navigation tools provided to identify the dry season crops that are best suited for their specific area. The portal will also provide crop husbandry, economic, and market information for each suitable dry season crop identified.

This webmap portal will be unique (novel) in that it will enable farmers to determine what crops can be grown in their specific areas during the dry season. Unlike the currently existing dry season crop guidelines, which only give a general list of the crops that can be grown during the dry season, the webmap will indicate the best suitable areas for each crop. Information about production, economics, and marketing of each identified crop will also be included in the webmap portal.

The design of these artifacts fits in the improvement quadrant of Gregor and Hevner (2013)'s grid of knowledge contribution as shown in Figure 1. The dry season food crises (production) problem has been known for a long time (high problem maturity), but the artifacts currently designed do not address the problem fully (low solution maturity). The interactive online webmap portal for Northeastern Thailand that will be designed in this research project will thus contribute to knowledge, particularly in the solution domain.

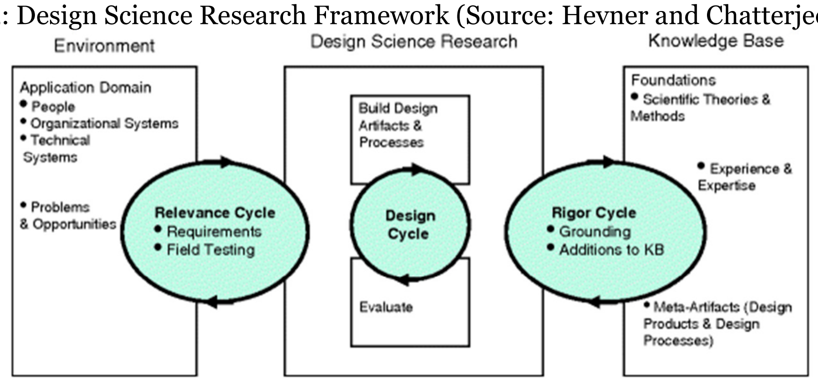
Figure 1: Design Science Knowledge Contribution (Source: Gregor and Hevner (2013, p.345))



Methodology

This study followed the design science research (DSR) methodology from Hevner and Chatterjee (2010) as shown in Figure 2. DSR consists of three research cycles: The Relevance Cycle, The Rigor Cycle, and The Central Design Cycle. Researchers interact with the three cycles interactively. For the first cycle, researchers connect the environment and design activities. The environment included problem domains that famers in the region are facing. Knowledge from problem domain was used to form the requirement of artifacts. For the second cycle, the design activities are connected with scientific knowledge, experience, and expertise. Knowledge base represents knowledge that was used to build the artifacts. It contains scientific knowledge from agriculture, remote sensing, and geographical information system. It also covers experience and expertise of the researchers. The last cycle suggests researchers iteratively connect building and evaluating the artifact with its processes (Hevner & Chatterjee, 2010).

Figure 2: Design Science Research Framework (Source: Hevner and Chatterjee (2010))



Design and Build

Artifact 1: Crop Choice Algorithm

A decision tree methodology was employed in the development of the algorithm. Based on previous literature, the algorithm consists of three factors: temperature, soil, and non-irrigated area.

Temperature was calculated using data sources from usgs.gov. Landsat 8 (usgs.gov) images were used to calculate land surface temperature. Three Python libraries were also used, namely: Numpy, Scipy, and Dnppy. ESRI's ArcGIS Desktop, including Model Builder was also used along with the following equations (1 to 7) to generate land surface temperature.

For the soil factor, soil data was obtained from the Food and Agriculture Organization (Potichan, 2012). Five soil classes were used to determine the area where each crop can be grown. These classes are 1) lowland, fine textured soils, 2) lowland, coarse to medium textured soils, 3) upland, fine textured soils, 4) upland, coarse to medium textured soils, and 5) upland, shallow soils.

$$NDVI = \frac{RED - NIR}{RED + NIR} \quad \text{--- (1)}$$

$$P_v = [\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}]^2 \quad \text{--- (2)}$$

$$\varepsilon = 0.004 P_v + 0.986 \quad \text{--- (3)}$$

$$L_\lambda = M_L Q_{cal} + A_L \quad \text{--- (4)}$$

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)} \quad \text{--- (5)}$$

$$\rho = h \times c / \sigma \quad \text{--- (6)}$$

$$S_t = \frac{T_B}{1 + (\lambda\, T_B / p)} \ln(\varepsilon) \quad \text{--- (7)}$$

Where

RED = Red wavelength

NIR = Near-infrared wavelength

P_v = Fraction Cover

ε = Spectral emissivity

M_L = Band-specific multiplicative rescaling factor

A_L = Band-specific additive rescaling factor from

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

L_λ = TOA spectral radiance (Watts/ (m2 * srad * μm))

K_1 = Band-specific thermal conversion constant

K_2 = Band-specific thermal conversion constant

T_B = At-satellite brightness temperature (K)

λ = Wavelength (band 10 or 11)

h = Planck's constant (6.626×10^{-34} J s)

σ = Boltzmann constant (1.38×10^{-23} J/K)

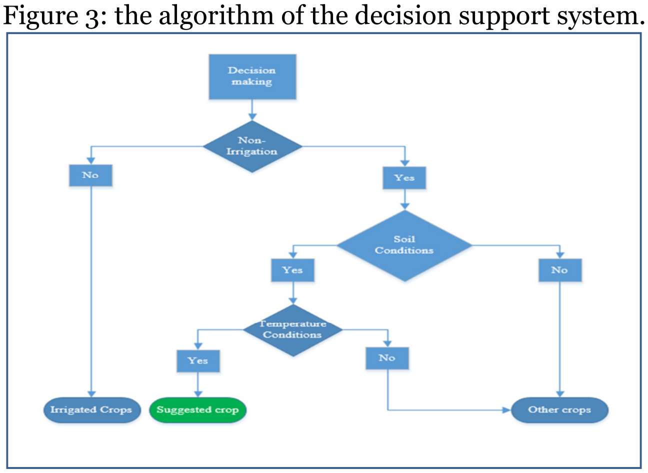
C = Velocity of light (2.998×10^{8} m/s)

S_t = Land Surface Temperature (K)

Sources: Artis and Carnahan (1982), Buhari (2015), Sobrino, Jiménez-Muñoz, and Paolini (2004), usgs.gov (2015), Weng, Lu, and Schubring (2004), and Yu, Guo, and Wu (2014). The equations are translated into ArcGIS Model Builder and used to generate the land surface temperature layer. The data were averaged between Nov 2014 and May 2015.

For the non-irrigated factor, data about irrigated and non-irrigated areas were obtained from diva-gis.org. The non-irrigated area in this research means the area where water resources (rivers, cannels, and reservoirs) are more than 100 meters from the area. The overall algorithm is shown in Figure 3 where: NIA = Non-irrigation Area; S = Soil Conditions; and T = Temperature Conditions.

Figure 3: the algorithm of the decision support system.

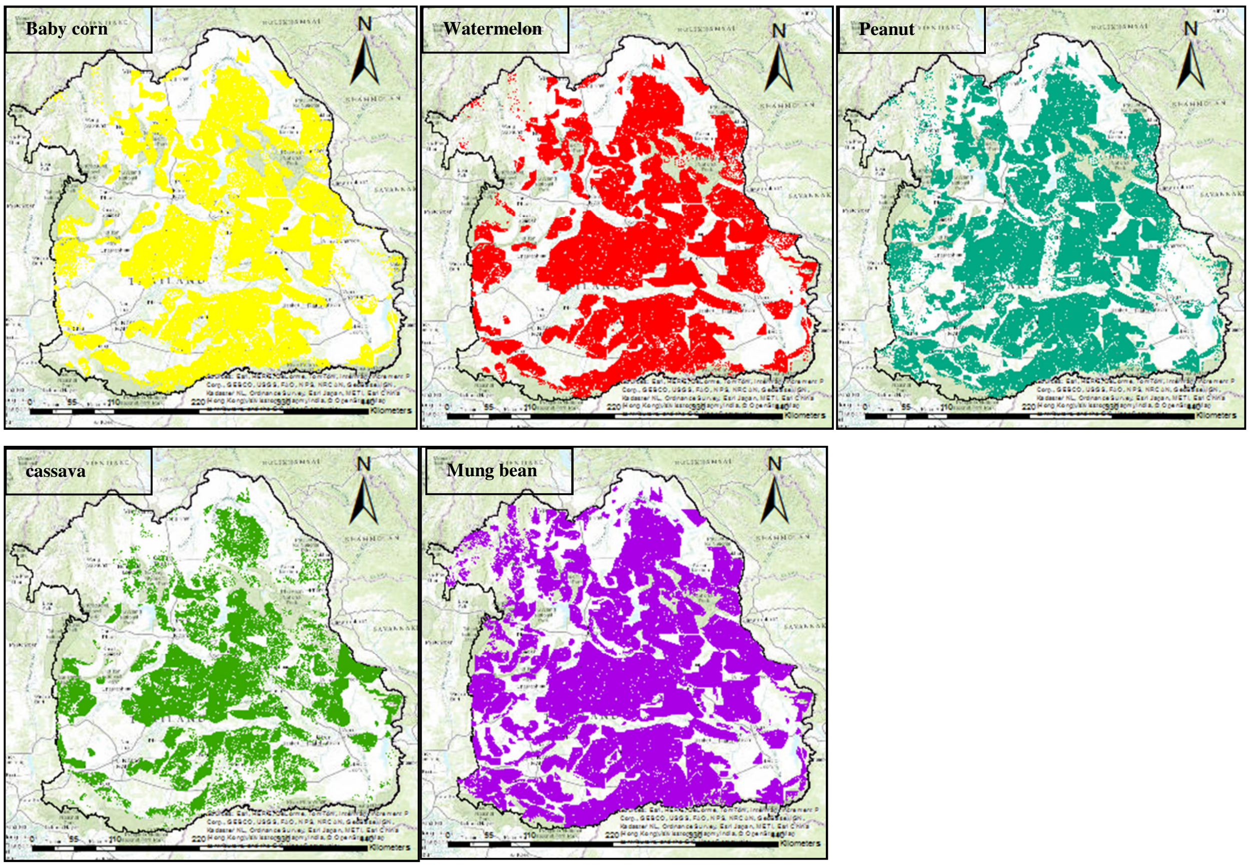


Note: each crop requires different parameters: the range of temperature and type of soils.
The algorithm can also be represented in set mathematics as the following equation:

$$Crop\ choice \propto NIA \cap S \cap T \qquad \text{--- (8)}$$

Equation 8 indicates that crop choice is related to the interaction among the three factors.

The results of the Artifact 1 are shown in the following pictures:



Artifact 2: Webmap Instantiation (future work)

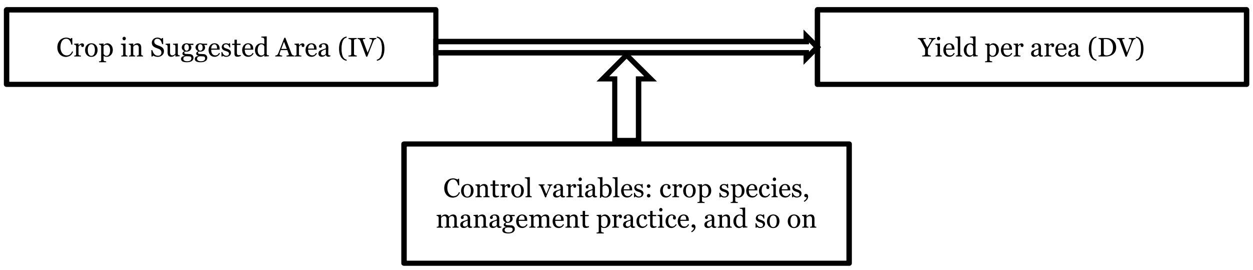
The instantiation (an interactive webmap) will be implemented in the future. The interactive webmap will be built on ArcGIS Online. The features will include marketing and economics variables, production costs and market prices. The webmap will be shared with Thai farmers. The webmap will suggest to farmers what and where each crop can be grown and how much they would gain from each suggested crop. In addition, information about how to market the crops will be included in the webmap. Additional future work will address the usefulness of the tool to farmers and how it will affect the adoption and diffusion of the innovation (Rogers 1983).

Evaluation

The algorithm was evaluated by two experts who gave their opinions and recommendations based on an expert-interview guide adopted from Hevner and Chatterjee (2010). The experts' interview responses are attached in the Appendix. The results of the evaluation show that the algorithm is useful, logical, and accurate. However, the accuracy test must be conducted before implementation of the decision support tool. Hence, two more evaluations, as enumerated below, will be carried out in the future.

1. Algorithm evaluation: A quasi-experiment designed as shown in the figure below will be conducted in Northeastern Thailand to evaluate the algorithm (Artifact 1) and establish whether crops grown in suggested areas provide higher yield per area than those grown outside the areas as shown in Figure 4.

Figure 4: Algorithm evaluation research design



2. Instantiation evaluation: The end-user evaluation of the interactive webmap (Artifact 2) will be conducted using System Usability Scale (Brooke, 1996). The Thai farmers in the area will evaluate the usefulness of the webmap.

Conclusion

Farmers in Northeastern region of Thailand leave their farms fallow during the dry season because they do not have adequate information on which dry-season crops are best suited for their specific areas, how to cultivate and manage those crops, and where to market them. Without adequate information and guidelines for dry season farming, farmers in this region will continue to leave their farms fallow and move to towns to look for other jobs during the dry season.

To help address this problem, this research has developed a decision support system in the form of an algorithm and interactive webmap that will enable farmers identify the best-suited dry season crops for their specific areas. Farmers will also be able to use the webmap to obtain crop husbandry, economic, and marketing information for the identified crops.

An initial expert evaluation for the decision support system was carried out. The recommendations given by the experts so far, and other experts' views, will be included in the decision support system in the future. Two other evaluations to determine the validity of the decision support system and the usability of the interactive webmap will be undertaken in the future.

Acknowledgements

We would like to thank Professor Dr. Andrew Marx and Professor Dr. Brian Hilton for their evaluation interviews. In addition, we would like to thank Tim Krug for his Python script used to clear up the satellite imagery and Komsan Rattanakijsuntorn for his evaluation of equations. Without them, the research would have been difficult to accomplish.

REFERENCES

Artis, D. A., and Carnahan, W. H. 1982. "Survey of emissivity variability in thermography of urban areas," *Remote Sensing of Environment* (12:4), pp. 313–329 (doi: 10.1016/0034-4257(82)90043-8).

Becu, N., Perez, P., Walker, A., Barreteau, O., and Page, C. L. 2003. "Agent Based Simulation of a Small Catchment Water Management in Northern Thailand: Description of the CATCHSCAPE Model," *Ecological Modelling* ISEM The third European Ecological Modelling Conference (170:2–3), pp. 319–331 (doi: 10.1016/S0304-3800(03)00236-9).

Brooke, J. 1996. "SUS: a 'quick and dirty' usability scale," in *Usability Evaluation In Industry*, CRC Press.

Buhari, U. 2015. "Landsat 8: Estimating Land Surface Temperature using ArcGIS," (available at https://www.youtube.com/watch?v=uDQo2a5e7dM; retrieved June 7, 2015).

Caldwell, J. S., Sukchan, S., and Ogura, C. 2005. "Management of Tropical Sandy Soils for Sustainable Agriculture," (available at http://www.fao.org/docrep/010/ag125e/AG125E10.htm; retrieved December 13, 2015).

Chainuvati, C., and Athipanan, W. 2001. "Crop Diversification in Thailand," Bangkok, Thailand: Food And Agriculture Organization of The United Nations Regional Office for Asia And The Pacific.

Craig, I. A., and Pisone, U. 1985. "Overview of Rainfed Agriculture in Northeast Thailand," in *Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand*, Presented at the The First KKU-USAID International Seminar, Khon Kaen,Thailand: Khon Kaen University.

Ekasingh, B., and Ngamsomsuke, K. 2009. "Searching for Simplified Farmers' Crop Choice Models for Integrated Watershed Management in Thailand: A data Mining Approach," *Environmental Modelling & Software*Special issue on simulation and modelling in the Asia-Pacific regionSI: ASIMMOD (24:12), pp. 1373–1380 (doi: 10.1016/j.envsoft.2009.02.015).

Ekasingh, B., Ngamsomsuke, K., Letcher, R. A., and Spate, J. 2005. "A Data Mining Approach to Simulating Farmers' Crop Choices for Integrated Water Resources management," *Journal of Environmental Management* Integrative modelling for sustainable water allocation (77:4), pp. 315–325 (doi: 10.1016/j.jenvman.2005.06.015).

fao.org. 2000. "Impact of Cassava Production onThe Environment," (available at http://www.fao.org/docrep/007/y2413e/y2413e07.htm; retrieved December 12, 2015).

fao.org. 2013. "Save and Grow: Cassava - 4. Water management," (available at http://www.fao.org/ag/save-and-grow/cassava/en/4/index.html; retrieved December 13, 2015).

fao.org. 2015a. "Crop Water Information: Watermelon," (available at http://www.fao.org/nr/water/cropinfo_watermelon.html; retrieved December 14, 2015).

fao.org. 2015b. "Crop Water Information: Groundnut," (available at http://www.fao.org/nr/water/cropinfo_groundnut.html; retrieved December 14, 2015).

Gregor, S., and Hevner, A. R. 2013. "Positioning and Presenting Design Science Research for Maximum Impact," *MIS Quarterly* (37:2), pp. 337–A6.

Hevner, A., and Chatterjee, S. 2010. *Design Research in Information Systems: Theory and Practice* Integrated Series in Information Systems (Vol. 22), New York: Springer.

Hollis, O. 2010. "More Accurate Peanut Maturity Measures Sought," (available at http://southeastfarmpress.com/peanuts/more-accurate-peanut-maturity-measures-sought; retrieved November 17, 2015).

Idhipong, S., Pong-sed, A., Maolanont, T., Wani, S. P., Rego, T. J., and Pathak, P. 2012. "Improved Crops and Cropping Systems for Rainfed Northeast Thailand," in *In Community watershed management for sustainable intensification in Northeast Thailand*, India: International Crops Research Institute for the Semi-Arid Tropics.

Limpinuntana, V. 1985. "Soil, Water and Crop Management Practices for Rainfed Agricultural Systems in Northeast Thailand," in *Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand*, Presented at the First KKU-USAID International Seminar, Khon Kaen,Thailand: Khon Kaen University.

Moniruzzaman, S. 2015. "Crop choice as climate change adaptation: Evidence from Bangladesh," *Ecological Economics* (118), pp. 90–98 (doi: 10.1016/j.ecolecon.2015.07.012).

Morton, F., Smith, R. E., and Poehlman, J. M. 1982. "The Mungbean," Puerto rico: U.S. Agency for International Development (available at http://pdf.usaid.gov/pdf_docs/PNAAL669.pdf).

National Statistical Office. 2003. "2003 Agricultural Census Northeastern Region," Ministry of Information and Communication Technology, p. 31.

Oplinger, E. S., Hardman, L. L., Kaminski, A. R., Combs, S. M., and Doll, J. D. 2015. "Mungbean," (available at http://corn.agronomy.wisc.edu/Crops/Mungbean.aspx; retrieved December 14, 2015).

Pinter, P. J., Hatfield, J. L., Schepers, J. S., Barnes, E. M., Moran, M. S., Daughtry, C. S. T., and Upchurch, D. R. 2003. "Remote Sensing for Crop Management," *Photogrammetric Engineering & Remote Sensing* (69:6), pp. 647–664.

Polthanee, A., and Marten, G. G. 1986. "Rainfed Cropping Systems in Northeast Thailand," in *Traditional Agriculture in Southeast Asia: A Human Ecology Perspective*, Boulder, Colorado: Westview Press.

Qingyuan, M., Chao, Z., Zhenghua, C., and Zhen, Y. 2007. "Management decision-making support system of percision agriculture based on CNCS," in *Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International*, Presented at the Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International, , July, pp. 819–822 (doi: 10.1109/IGARSS.2007.4422922).

Ratanawaraha, C., Senanarong, N., and Suriypan, P. 2000. "A Review Of Cassava In Asia With Country Case Studies on Thailand and Viet Nam," (available at http://www.fao.org/docrep/009/y1177e/y1177e04.htm; retrieved December 13, 2015).

Rogers, E. M. 1983. *Diffusion of Innovations* (3rd ed.), New York: The Free Press.

Rosen, C., and Fritz, V. 2015. "Growing Melons (Cantaloupe, Watermelon, Honeydew) in Minnesota Home Gardens," (available at http://www.extension.umn.edu/garden/yard-garden/fruit/growing-melons-in-minnesota-home-gardens/; retrieved December 14, 2015).

Simpson, M. 2015. "How Long Does Watermelon Take to Grow & What Month Do You Plant?," (available at http://homeguides.sfgate.com/long-watermelon-grow-month-plant-51141.html; retrieved November 17, 2015).

Sobrino, J. A., Jiménez-Muñoz, J. C., and Paolini, L. 2004. "Land Surface Temperature Retrieval from LANDSAT TM 5," *Remote Sensing of Environment* (90:4), pp. 434–440 (doi: 10.1016/j.rse.2004.02.003).

Sukharomana, S., and Dobkuntod, B. 2003. "Peanut in the Thai Food System: A Macro Perspective," Athens, Georgia: University of Geogia.

thailandforvisitors.com. 2015. "Watermelon - Thailand for Visitors," (available at http://thailandforvisitors.com/general/food/fruit/watermelon.html; retrieved November 17, 2015).

Thanawong, k, Perret, S. R., and Basset-Mens, C. 2014. "Eco-efficiency of paddy rice production in Northeastern Thailand: a comparison of rain-fed and irrigated cropping systems," *Journal of Cleaner Production* (73), pp. 204–217.

The World Bank. 2015. "Food Security," (available at http://www.worldbank.org/en/topic/foodsecurity; retrieved September 27, 2015).

Titapiwatanakun, B. 2012. "The Rice Situation in Thailand," Technical Assistance Consultant's Report, , Asian Development Bank.

usgs.gov. 2015. "Using the USGS Landsat 8 Product," (available at http://landsat.usgs.gov/Landsat8_Using_Product.php; retrieved December 15, 2015).

Vinje, E. 2012. "How to Grow Watermelon from Seeds," *Planet Natural* (available at http://www.planetnatural.com/growing-watermelon/; retrieved December 14, 2015).

volkerkleinhenz.com. 2006. "Baby corn production, processing and marketing in Thailand," (available at http://www.volkerkleinhenz.com/publications/baby-corn-production-processing-and-marketing-in-thailand/baby-corn-production-processing-and-marketing-in-thailand.pdf; retrieved December 14, 2015).

Weng, Q., Lu, D., and Schubring, J. 2004. "Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies," *Remote Sensing of Environment* (89:4), pp. 467–483 (doi: 10.1016/j.rse.2003.11.005).

wikipedia.org. 2015. "Peanut," *Wikipedia, the free encyclopedia*, December 12 (available at https://en.wikipedia.org/w/index.php?title=Peanut&oldid=694978593; retrieved December 14, 2015).

World Economic Forum. 2015. "Global Risks 2015:10th Edition," Geneva: World Economic Forum, p. 66.

Yu, X., Guo, X., and Wu, Z. 2014. "Land Surface Temperature Retrieval from Landsat 8 TIRS—Comparison between Radiative Transfer Equation-Based Method, Split Window Algorithm and Single Channel Method," *Remote Sensing* (6:10), pp. 9829–9852.

Appendix

Expert's Evaluation Interviews Guide:

Q1: What is your opinion about the algorithm?
E1: The model [algorithm] is good since it answers your research question – how to inform farmers which crops are suitable for their land.
E2: Overall, the model [algorithm] is great; it is thought out well. The model makes sense, in particular the Venn diagram. You should also look for the "Seasonal Hazard Calendar" from FAO which shows seasonal hazards and calendars. It is just another check and one way to improve.
Q2: How can we improve the algorithm?
E1: The model [algorithm] can be improved by adding slope and setting a threshold above which no crops can be grown. You also need to deal with the mosaic issues and consider other available and easier methods of getting surface temperature, for example, using 16-day or annual surface temperature data products that are already packaged.
E2: You should get more data from Landsat imagery to average more temperature values [more seasons].
Q3: Is the algorithm accurate?
E1: I think so if it was done according to the literature but, before implementing the model you need to carry out an accuracy assessment test to validate the model [algorithm] based on the current farming practices. You should check if the model predictions are consistent with what is actually happening on the ground. You may need to tweak the model based on this feedback and rerun the model multiple times to get the best accuracy.
E2: Yes, this [algorithm] seems correct. One-way to evaluate the model, maybe, you should go to Thailand, interview the farmers, and show them the maps.
Q4: Is the algorithm useful?
E1: Yes it is useful especially because it is targeting individual farmers and not the central government officers.
E2: Yes, the mode [algorithm] l seems to be useful to me.
Q5: Do you have any recommendation?
E1: You should use Global Land Data from usgs.gov to determine irrigated crop areas [and non-irrigated areas]. Double check your method for calculating land surface temperature. Rather than drawing from raw images from Landsat, you should look for what other people or experts have processed and use their datasets instead.
E2: You should contact FAO for soil classification map. You should generalize the model to make it more applicable to other areas apart from Northeastern Thailand. You should also include a text messaging application that alerts farmers about crop market prices. The applications should connect farmers and brokers. Brokers can send the price that they want to purchase and then farmers can decide what they should grow in the following dry-season in the next five months. I think this is great. It is a very good project to continue.